Channel Widening and Flood-Plain Construction Along Cimarron River in Southwestern Kansas

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By S. A. SCHUMM *and* R. W. LICHTY

EROSION AND SEDIMENTATION IN A SEMIARID ENVIRONMENT

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Major channel changes along the Cimarron River are related to the frequency and magnitude of floods and the departure of annual precipitation from normal

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CHANNEL WIDENING AND FLOOD-PLAIN CONSTRUCTION ALONG CIMARRON RIVER IN SOUTHWESTERN KANSAS

By S. A. Schumm and R. W. Lichty

ABSTRACT

The channel of the Cimarron River in southwestern Kansas has changed significantly during historic times. The average width of the river was 50 feet in 1874. During and after the major floor of 1914, the river widened until an average width of 1,200 feet was reached in 1942. During the period 1943–54 flood-plain construction occurred, and the river narrowed to an average width of 550 feet in 1954. During the period 1954–60 both channel widening and narrowing occurred.

The period of channel widening was initiated by the maximum flood of record, which was followed by a long period of deficient precipitation, and was terminated by the major flood of 1942. The period of flood-plain construction was characterized by above-average annual precipitation and floods of low to moderate peak discharge. The influence of the changed climatic conditions on vegetational growth is the key to Cimarron River behavior. During the years of above-average annual precipitation, which are associated with floods of low to moderate peak discharge, vegetation became established in the wide sandy channel. The presence of vegetation in the channel in turn aided deposition and flood plain formation.

The new flood plain was constructed in a period of 12 years, predominantly by vertical accretion. It is composed of a mosaic of islands, abandoned channels, and areas of flood plain constructed adjacent to the low-water channel. Although initially a flood plain may be formed by overbank flooding and vertical accretion, lateral migration of the stream may rework the alluvium and destroy all evidence of vertical accretion.

The channel changes which have occurred along Cimarron River seem typical of sandy rivers in semiarid regions. Channel widening instead of degradation and channel narrowing instead of aggradation are characteristic.

INTRODUCTION

Flood plains are of historic interest to man. They offered fertile land, abundant water, and game to the primitive hunter and agriculturalist and became sites of early civilizations. The flood-plain dweller of today faces many of the same problems as did his ancestors. For this reason a better understanding of river and flood-plain changes may be helpful in preventing a repetition of past disasters.

Geomorphic processes proceed at rates that generally are difficult to assess, and the opportunity seldom arises to obtain data on the rates. Nevertheless, a record of modern flood-plain destruction and rebuilding is available for the Cimarron River in southwestern Kansas. This record of stream-channel and flood-plain changes, the reasons for the changes, and a description of the mechanics of the changes are presented in this report as a contribution toward a better understanding of fluvial erosion and deposition in a semiarid region.

The Cimarron River enters western Kansas about 5 miles north of the Oklahoma boundary (fig. 42) and flows northeastward through Morton, Stevens, and Grant Counties and then southeastward through Haskell, Seward, and Meade Counties before reentering Oklahoma. The Cimarron Valley in southwestern Kansas is underlain almost completely by rocks of Tertiary and Quaternary age, although small outcrops of Triassic and Cretaceous rocks occur in Morton County. The geology and ground-water resources of this area have been discussed by McLaughlin (1942, 1946), Bryne and McLaughlin (1948), and Frye (1942).

The initial widening of the Cimarron River, after the major flood of 1914, was discussed by McLaughlin (1947); his paper directed the writers' attention to the interesting series of events that have occurred along this river during the last half century.

The writers wish to acknowledge particularly the suggestions and encouragement of T. G. McLaughlin, as well as the use of his photographs (figs. 43*B*, 44*A*). Messrs. Robert Evans and Rice Davies of Liberal, Kans., very kindly gave us the benefit of their knowledge of river changes since the 1914 flood. Richard Aro instructed the writers in the techniques of tree-ring counts and made valuable suggestions with respect to the interpretation of these data.

CIMARRON RIVER, SOUTHWESTERN KANSAS, 1874–1960

CIMARRON RIVER, 1874–1913

The Cimarron River in Kansas appeared to be typical of streams in a more humid environment at the turn

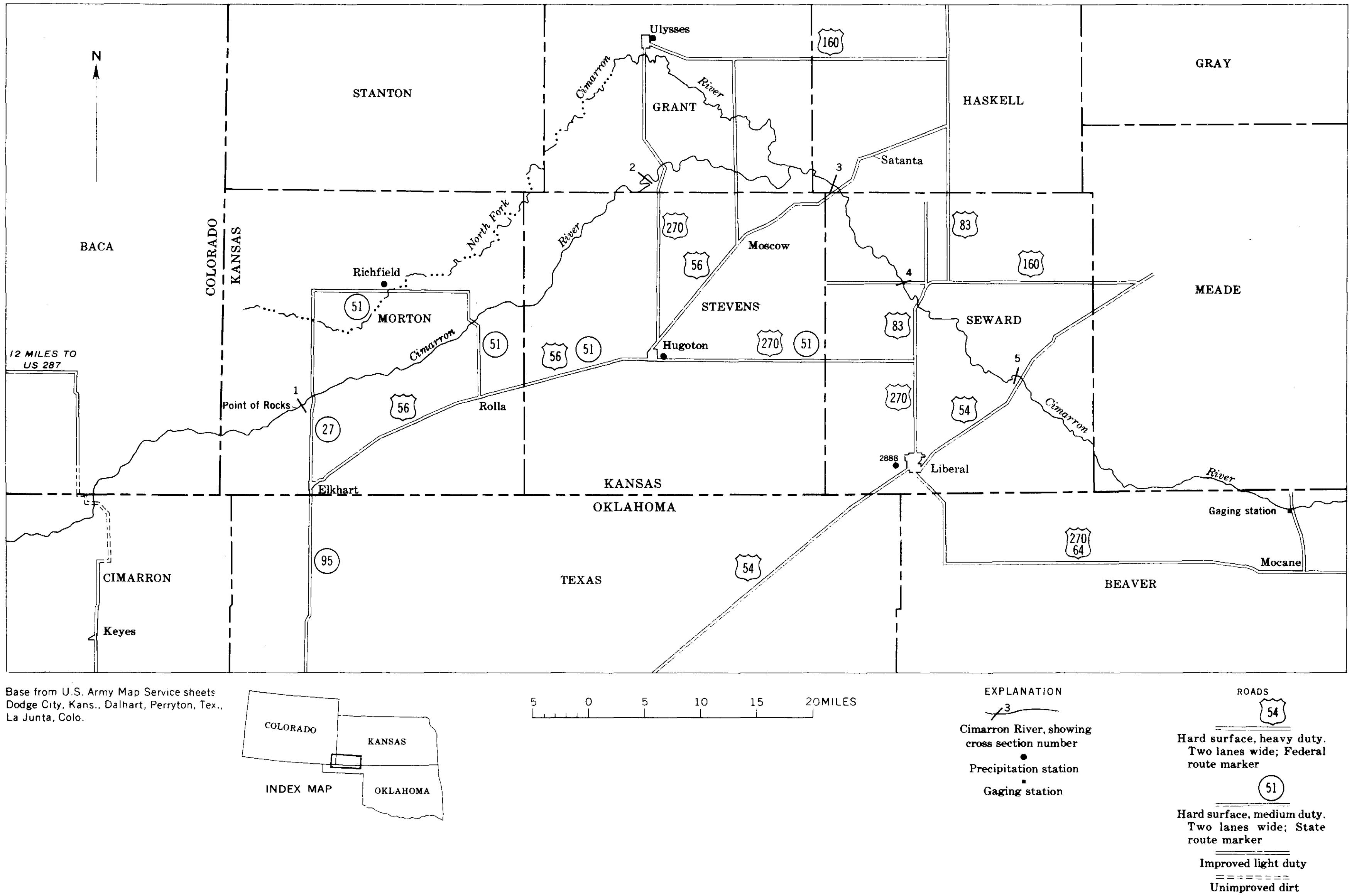

FIGURE 42.—Index map of Cimarron River area.

of the century. Haworth (1897, p. 22) stated that "The Cimarron seems to have reached base-level and to have begun meandering across its flood plain. Beautiful ox-bow curves are frequent, and a sluggish nature is everywhere manifest during times of low water." (See fig. 43*A*.)

According to Johnson (1902, p. 664),

> Wherever within the High Plains belt the Cimarron Valley shows a living stream, it is always a meandering looping stream of uniform width, narrow, clear and deep * * *. The bottom land upon which it wanders supports a coarser and longer-stemmed grass than the uplands, the grass roots reaching to the ground water, which lies at a depth here, as a rule, of only 2 or 3 feet * * *.

The Cimarron River elsewhere, upstream to the southwest in the Oklahoma Panhandle and downstream to the southeast in Oklahoma, during historic times has always been typically a wide, shallow, sandy river. As suggested by Johnson, the great difference between the Cimarron River in Kansas and the river elsewhere may be that, in Kansas, a perennial flow was maintained by ground water. Additional testimony, confirming that the Cimarron River was a narrow, meandering perennial stream at the turn of the century, was presented by McLaughlin (1947).

Information on the width of the Cimarron River is available as a result of the survey of 1874. The data were compiled by McLaughlin (1947), and data for 120 cross sections are presented in table 1. Thirty-five of the 155 sections originally listed by McLaughlin were not remeasured; therefore, the mean values for channel widths by counties as presented in table 1 will differ slightly from those presented by McLaughlin (1947).

TABLE 1.—*Channel width, in feet, of the Cimarron River, Kans.*

[Channel width: 1874 and 1939, data from McLaughlin (1947); 1954, data from aerial photographs, scale 1:27,250; 1960, data from photomosaic sheets, scale 1:63,360; *n* equals number of sections measured]

Section	Location	Channel width			
		1874	1939	1954	1960
	Morton County				
	T. 34 S., R. 43 W.				
1	West line sec. 19	53	2,900	1,050	1,250
2	West line sec. 20	53	3,000	1,050	1,350
3	West line sec. 21	46	3,200	1,500	1,500
4	West line sec. 22	40	2,800	700	900
5	North line sec. 22	33	2,100	1,500	1,650
6	West line sec. 14	79	1,800	1,000	1,400
7	East line sec. 14	66	2,300	1,200	1,400
	T. 34 S., R. 42 W.				
8	West line sec. 7	139	1,300	800	900
9	East line sec. 7	66	2,150	1,000	1,100
10	East line sec. 5	59	1,400	650	650
11	East line sec. 4	46	2,600	400	400
12	North line sec. 3	73	1,800	1,100	1,200
	Morton County—Continued				
	T. 33 S., R. 42 W.				
13	West line sec. 35	46	3,200	950	800
14	North line sec. 35	46	800	850	850
15	East line sec. 26	46	800	650	650
	T. 33 S., R. 41 W.				
16	West line sec. 29	66	2,200	350	350
17	West line sec. 28	66	2,600	500	1,100
18	East line sec. 28	46	1,100	1,000	1,200
19	South line sec. 22	66	1,500	500	500
20	West line sec. 23	66	2,000	850	1,050
21	West line sec. 24	66	2,400	1,000	1,100
22	NE corner sec. 24	46	2,500	1,650	1,650
	T. 33 S., R. 40 W.				
23	East line sec. 18	33	300	250	250
24	South line sec. 8	33	2,100	1,000	1,000
25	West line sec. 9	66	2,900	800	900
26	SW corner sec. 3	56	2,400	450	450
27	NE corner sec. 3	43	2,600	1,000	800
	T. 32 S., R. 40 W.				
28	NE corner sec. 35	33	1,100	150	150
	T. 32 S., R. 39 W.				
29	West line sec. 30	46	2,600	550	800
30	East line sec. 30	53	1,300	400	650
31	East line sec. 29	53	1,400	250	300
	Average for Morton County ($n=31$)	56	2,050	800	900
	Stevens County				
	T. 32 S., R. 39 W.				
32	West line sec. 27	53	2,200	700	1,300
33	West line sec. 26	46	2,500	400	600
34	North line sec. 26	46	2,100	1,500	800
35	NE corner sec. 23	36	2,200	650	900
36	North line sec. 13	33	1,800	700	1,000
37	North line sec. 12	40	700	500	500
	T. 31 S., R. 38 W.				
38	SW corner sec. 29	46	1,300	850	600
39	SW corner sec. 21	40	1,700	300	400
40	North line sec. 21	46	1,000	500	800
41	West line sec. 15	40	1,100	550	800
42	NE corner sec. 15	46	800	300	800
	Average for Stevens County ($n=11$)	43	1,500	630	770
	Grant County				
	T. 30 S., R. 37 W.				
43	West line sec. 32	26	600	250	250
44	West line sec. 33	40	500	150	150
45	West line sec. 34	40	600	250	250
46	South line sec. 28	40	500	150	150
47	West line sec. 27	50	800	150	150
48	North line sec. 34	66	800	150	150
49	West line sec. 35	132	300	100	100
50	South line sec. 26	99	400	100	100
51	South line sec. 23	66	500	100	100
52	West line sec. 24	66	300	200	200
53	North line sec. 25	66	700	150	150
	T. 30 S., R. 36 W.				
54	West line sec. 21	66	200	200	200
55	West line sec. 22	66	300	400	400
56	West line sec. 23	66	500	150	150
	T. 30 S., R. 35 W.				
57	West line sec. 34	26	1,300	150	150
58	South line sec. 27	26	1,300	650	650
59	SW corner sec. 23	17	1,100	100	100
60	North line sec. 26	33	700	100	100
61	West line sec. 25	43	500	100	100
	Average for Grant County ($n=19$)	54	630	190	190

TABLE 1.—*Channel width, in feet, of the Cimarron River, Kans.*—Continued

Section	Location	Channel width			
		1874	1939	1954	1960
	Haskell County				
	T. 30 S., R. 34 W.				
62	North line sec. 30	33	800	100	100
63	East line sec. 30	33	500	200	200
64	South line sec. 29	33	500	200	200
65	East line sec. 32	26	300	450	600
66	South line sec. 33	33	300	300	200
	Average for Haskell County (*n*=5)	32	480	250	260
	Seward County				
	T. 31 S., R. 34 W.				
67	North line sec. 8	66	300	200	1,200
68	North line sec. 21	33	600	1,000	1,400
69	North line sec. 28	20	1,400	800	800
70	West line sec. 27	66	1,000	400	400
71	North line sec. 34	132	1,000	700	700
72	West line sec. 35	43	1,500	500	500
73	West line sec. 36	33	1,600	1,000	1,000
74	South line sec. 36	13	1,000	400	400
	T. 32 S., R. 33 W.				
75	West line sec. 6	16	1,100	250	550
76	North line sec. 7	15	1,200	800	900
77	North line sec. 18	16	300	150	150
78	West line sec. 17	16	1,000	700	700
79	North line sec. 20	18	1,000	400	400
80	West line sec. 21	18	600	300	300
81	North line sec. 28	16	1,100	150	150
82	West line sec. 27	16	900	400	400
83	North line sec. 34	13	500	400	500
84	West line sec. 35	10	1,000	500	500
85	West line sec. 36	13	1,300	500	500
86	South line sec. 36	20	500	100	100
	T. 33 S., R. 32 W.				
87	West line sec. 6	49	500	200	200
88	North line sec. 7	13	700	550	300
89	North line sec. 18	33	1,800	1,200	1,200
90	South line sec. 18	13	440	300	300
91	East line sec. 20	20	1,410	300	400
92	South line sec. 21	26	370	300	300
93	West line sec. 27	26	790	500	400
94	West line sec. 26	20	1,100	700	800
95	West line sec. 25	33	350	100	100
96	North line sec. 36	33	1,320	150	150
97	East line sec. 36	33	1,180	800	800
	T. 33 S., R. 31 W.				
98	South line sec. 31	33	880	300	900
	T. 34 S., R. 31 W.				
99	West line sec. 5	20	1,320	400	600
100	West line sec. 9	20	270	200	800
101	North line sec. 16	20	1,140	250	400
102	West line sec. 15	26	260	250	250
103	North line sec. 22	26	1,230	300	650
104	SE corner sec. 15	33	970	300	400
105	SE corner sec. 23	30	620	200	300
106	East line sec. 25	33	570	500	500
	Average for Seward County (*n*=40)	28	900	440	530
	Meade County				
	T. 34 S., R. 30 W.				
107	South line sec. 30	33	1,050	300	500
108	South line sec. 31	79	570	400	200
	T. 35 S., R. 30 W.				
109	East line sec. 6	40	1,320	300	300
110	South line sec. 5	43	1,410	300	300
111	South line sec. 9	53	530	350	350
112	East line sec. 16	33	1,250	300	300
113	East line sec. 15	33	800	700	700
114	East line sec. 14	66	1,000	1,400	1,400
115	East line sec. 13	132	1,000	2,000	2,000
	Meade County—Continued				
	T. 35 S., R. 29 W.				
116	East line sec. 18	100	1,100	1,300	1,300
117	East line sec. 9	93	1,600	1,200	900
118	East line sec. 10	145	1,000	950	600
119	East line sec. 11	304	1,300	750	750
120	East line sec. 13	132	800	1,650	1,650
	Average for Meade County (*n*=14)	92	1,050	850	800
	Average width for 120 sections	50	1,200	550	600

In 1874 the river averaged 50 feet in width through the 6 counties of southwestern Kansas; however the channel ranged in width from 10 to 304 feet (table 1). Some of the variation in width is due to the fact that measurement of channel width was made along section lines which were not normal to the channel. Nevertheless, the channel of the river in Kansas between 1874 and 1914 was narrow and probably relatively stable. The flood plain was grassed and afforded excellent grazing. Wild hay and alfalfa were cut and stacked on the flood plain during these early days (fig. 43*A*). The contrast between the river at that time and during the following 46 years is remarkable.

CIMARRON RIVER, 1914–42

Beginning in 1914 and continuing intermittently until 1942, the channel of the Cimarron River widened, until almost all the flood plain was destroyed. The channel widening began, according to the testimony of residents of the Cimarron valley, during the major flood of May 1914. This flood is the greatest of record, having an estimated gage height of 13 feet near Mocane, Okla. (fig. 42); peak discharge is estimated to have been 120,000 cfs (cubic feet per second). (See table 2.)

During the 1874 survey, the channel north of Elkhart was 66 feet wide (fig. 42). Only minor changes in width occurred between 1874 and 1914; however, in 1916 a bridge 644 feet long was required to span the channel, and in 1939 the channel at the bridge was about 1,400 feet wide (McLaughlin, 1947, p. 82). The data presented on table 1 show that the average channel widening during the period 1914–39 was 1,150 feet.

Although no aerial photographs are available to document channel changes between 1939 and 1954, other data indicate that the channel continued to widen through 1942. For example, a major flood near Liberal, Kans., occurred in 1942 with a peak discharge of 69,000 cfs. This flood originated in the headwaters

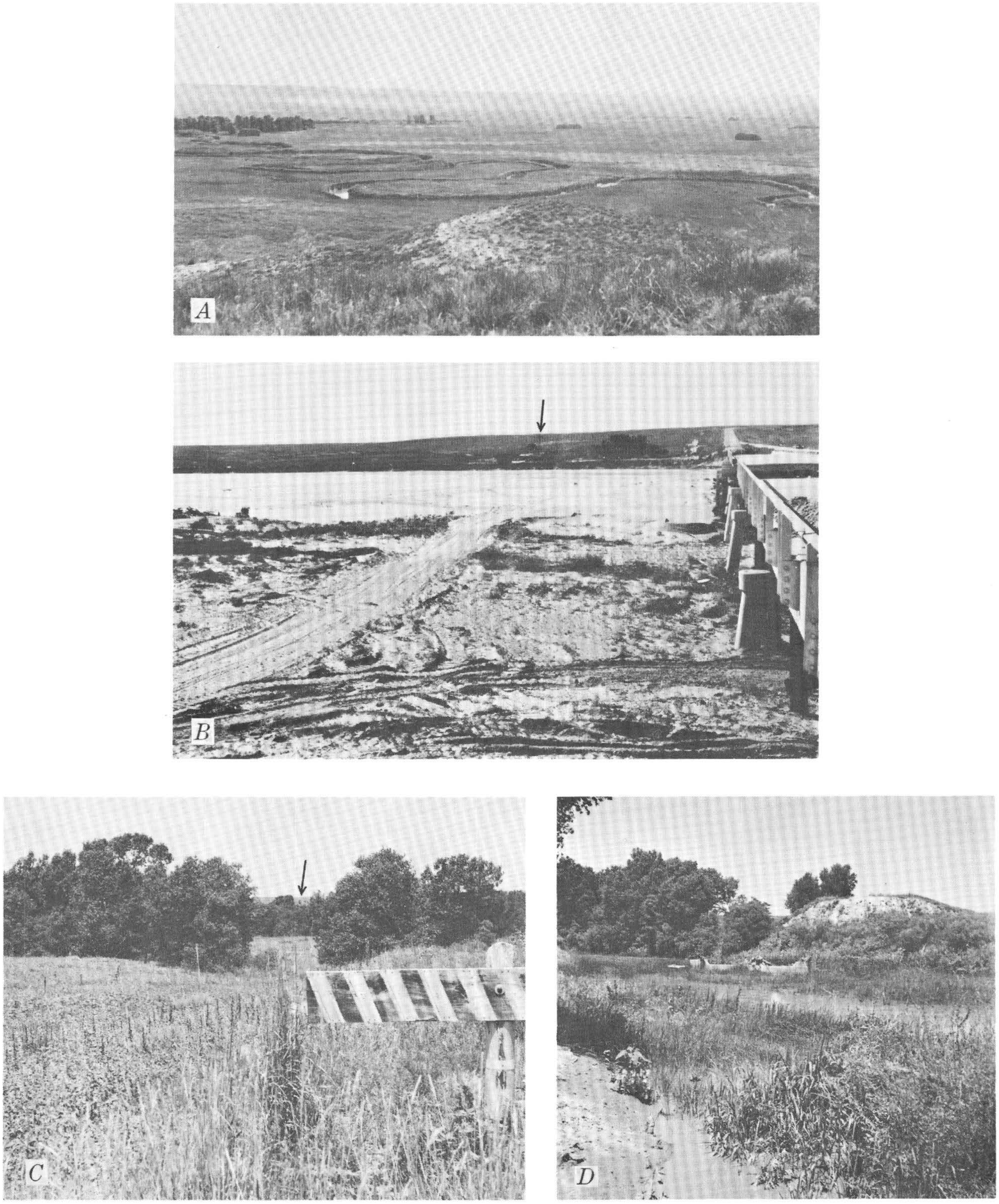

FIGURE 43.—Cimarron River in southwestern Kansas. *A,* Valley of Cimarron River in southeastern Meade County, Kans., prior to the flood of 1914. Photograph taken by W. D. Johnson in the 1890's. *B,* Cimarron River at old Highway 270 bridge north of Hugoton, Kans. (cross section 2, fig. 42), in 1943. Channel was about 700 feet wide. Arrow indicates position of windmill. Photograph taken by T. G. McLaughlin. *C,* Valley of Cimarron River at old Highway 270 bridge in 1960. Arrow indicates position of windmill shown in *B.* Trees in foreground are growing in abandoned channel shown at right end of profile *B–B'* (fig. 47). Present channel is beyond trees in background. *D,* Channel of Cimarron River at old Highway 270 bridge in 1960. Channel is 110 feet wide. Compare channel shown in this view with channel in 1943 shown in *B.*

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area (peak discharge 80,000 cfs near Boise City, Okla.) and destroyed many bridges as it moved through the Cimarron River valley in Kansas. At the close of 1942 the river was at its maximum width, for the flood plain was completely destroyed at some locations. Good evidence for complete destruction of the flood plain north of Hugoton, Kans. (fig. 42), is provided by a photograph taken of the channel in 1943 (fig. 43*B*). At that time the entire valley floor was river channel. The present channel is only 110 feet wide and is located at the north edge of what was the 1942 channel (fig. 43*C*). The trees in the foreground of figure 43*C* began their growth at the south edge of the channel in 1943, as indicated by tree-ring counts. The survival of these trees is proof that the channel was never again as wide as it was after the 1942 flood.

CIMARRON RIVER, 1943–54

After the flood of 1942, a reversal of river activity occurred. Cross sections, when remeasured on aerial photographs taken in 1954, showed that the channel had become narrower (table 1). The narrowing was accomplished by flood-plain construction and, to a minor extent, by island formation. The channel width, as measured on the 1954 photographs, had decreased to an average of 550 feet (fig. 43*C*, 43*D*, 44*A*, *B*).

In 12 years the river had repaired about half the damage caused by widening during the period 1914–42. Great variability occurs among the data. At some cross sections the river narrowed to one-fifth or less of its former maximum width (table 1, sections 11, 16, 17, 31, 33, 47, 48, 51, 57, 59, 60, 61, 62, and 81), whereas at other cross sections the river width did not change (table 1, sections 54 and 66) or continued to widen (table 1, sections 14, 55, 65, 68, 114, 115, 116, and 120).

CIMARRON RIVER, 1955–60

New aerial photographs, which became available during preparation of this report, allowed measurements to be made of 1960 channel widths. The measurements were made on photoindex sheets and are less accurate than those made from contact prints of the 1954 photographs. The measurements show, however, that the period 1954–60 was not a continuation of the period 1943–54. Of 120 sections remeasured, only 10 showed continued narrowing of more than 50 feet (Table 1, sections 13, 27, 34, 38, 66, 88, 93, 108, 117, and 118); 70 sections were at about the same width; and of the remaining 40 sections, 38 showed renewed widening of more than 50 feet, whereas sections 65 and 68 have continued to widen since the first survey in 1874. The period may be characterized as one of relative stability with some tendency toward widening of the channel.

SUMMARY

The major changes in width of the Cimarron River during the 46-year period 1914–60 can be grouped into 3 distinct periods: the period 1914–42 of channel widening and flood-plain destruction (figs. 43 and 44); the period 1943–54 of channel narrowing and flood-plain construction; and the period 1955–60 of relatively minor changes (figs. 43 and 44).

The channel widening along the Cimarron River may be related to arroyo cutting, which has been prevalent throughout the Southwest since the latter part of the 19th century. However, there are two major differences between arroyo cutting and the channel changes along the Cimarron River. One is the nature of the change, widening instead of predominant deepening. The other is a trend toward rapid natural restoration of the valley to its former condition.

FACTORS INFLUENCING CIMARRON RIVER CHANNEL CHANGES

The causes of natural phenomena of the type discussed in this paper are generally complex and varied. Nevertheless, all available information will be considered in an attempt to explain the cause of destruction and rebuilding of the Cimarron River flood plain.

LAND USE

McLaughlin (1947), after an analysis of information on number of head of livestock and acres of cultivated land in southwestern Kansas, suggested that "accelerated erosion in the Cimarron valley is believed to be the result of overcultivation of land and the subsequent abandonment of thousands of farms, leaving large areas with lessened resistance to run-off." Unfortunately, there is little information on runoff for the period of channel widening. McLaughlin's data, when brought up to date (fig. 45), indicated that the period of flood-plain construction occurred during a period of major agricultural activity, 1941–50. This peak of agricultural activity probably began with the demand for more agricultural products during the war. The period 1941–50 was also a time of above average annual precipitation (fig. 46), a further stimulus to agricultural activity during these years. This coincidence of flood-plain construction and agricultural activity would seem to support McLaughlin's hypothesis; however, a shorter period of major agricultural activity also occurred between the years 1929–33 (fig. 45) during the period of channel widening. On the basis of these conflicting data, it is difficult to evaluate the effects of agricultural activity on the Cimarron River.

McLaughlin (1947) also concluded that, because there was no major change in number of head of livestock, grazing was not an important factor determining channel changes. Data on number of livestock in southwestern Kansas are presented on figure 45. Livestock density was greatest during the period of channel narrowing 1942–48. The activities of man and animals in the Cimarron River basin undoubtedly had their effects on the regime of the river, but any relation between cultivation, grazing, and channel change is obscure.

FLOODS

The period of greatest channel widening began in 1914 and ceased in 1942. Unfortunately, adequate streamflow data are not available during the period of channel widening to establish a definite trend, but the record presented in table 2 shows that large floods occurred in 1936, 1938, 1941, and 1942. Furthermore, according to C. O. Bryant (written communication),

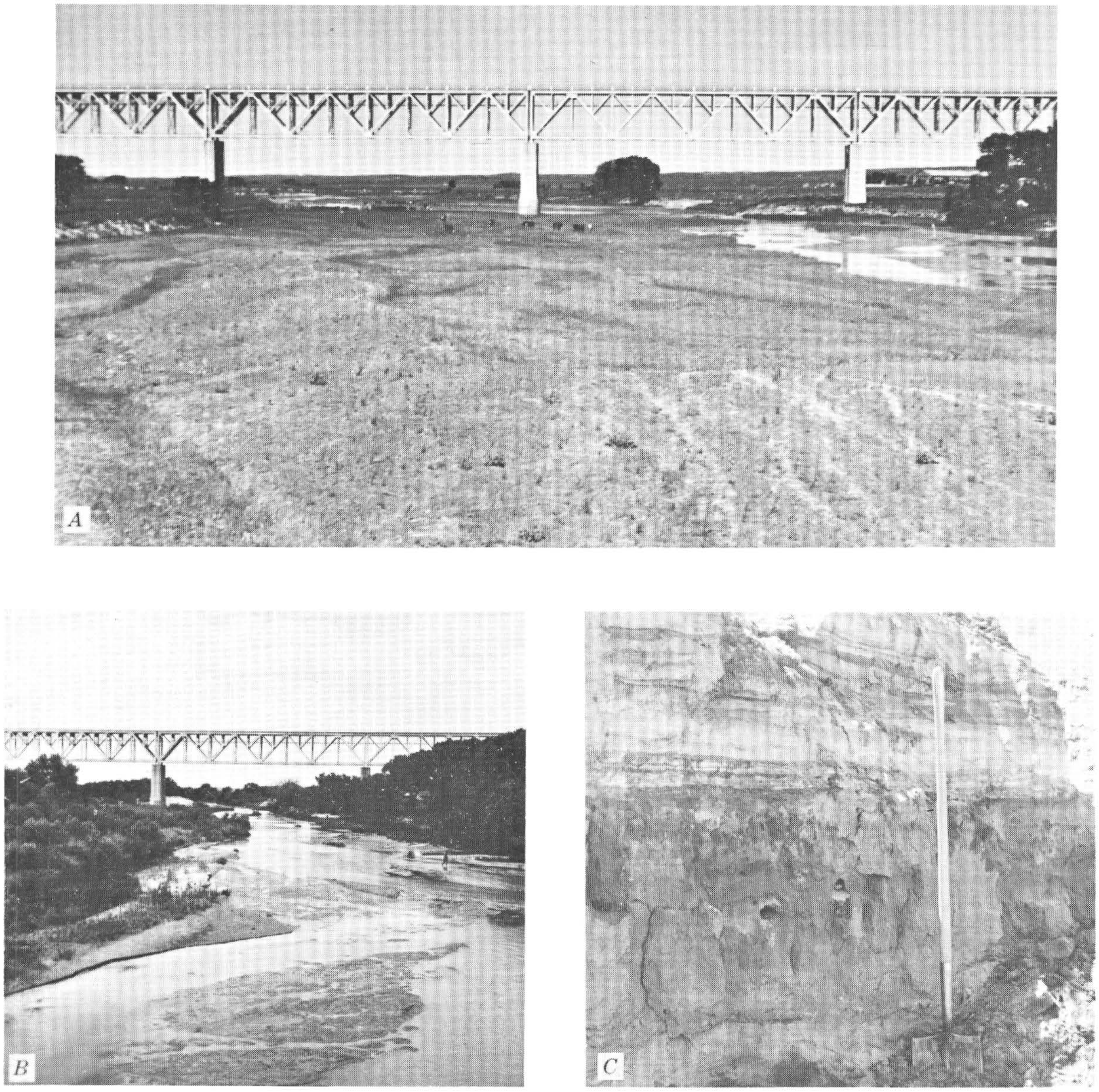


FIGURE 44.—Cimarron River in southwestern Kansas. *A*, Rock Island Railroad bridge near Arkalon in 1942. Channel was about 450 feet wide at point from which photograph was taken. Photograph taken by T. G. McLaughlin. *B*, Rock Island Railroad bridge near Arkalon in 1960. Channel is about 150 feet wide. Concrete bridge support on left of this photograph corresponds to center support shown in *A*. *C*, Pre-1914 alluvium exposed in cutbank near Highway 56 crossing. At base of cut is coarse crossbedded sand. Above sand is 2.5 feet of dark-colored homogeneous cohesive pre-1914 alluvium. Overlying the pre-1914 alluvium is 3 feet of alternate layers of sand and mud deposited from overbank floods.

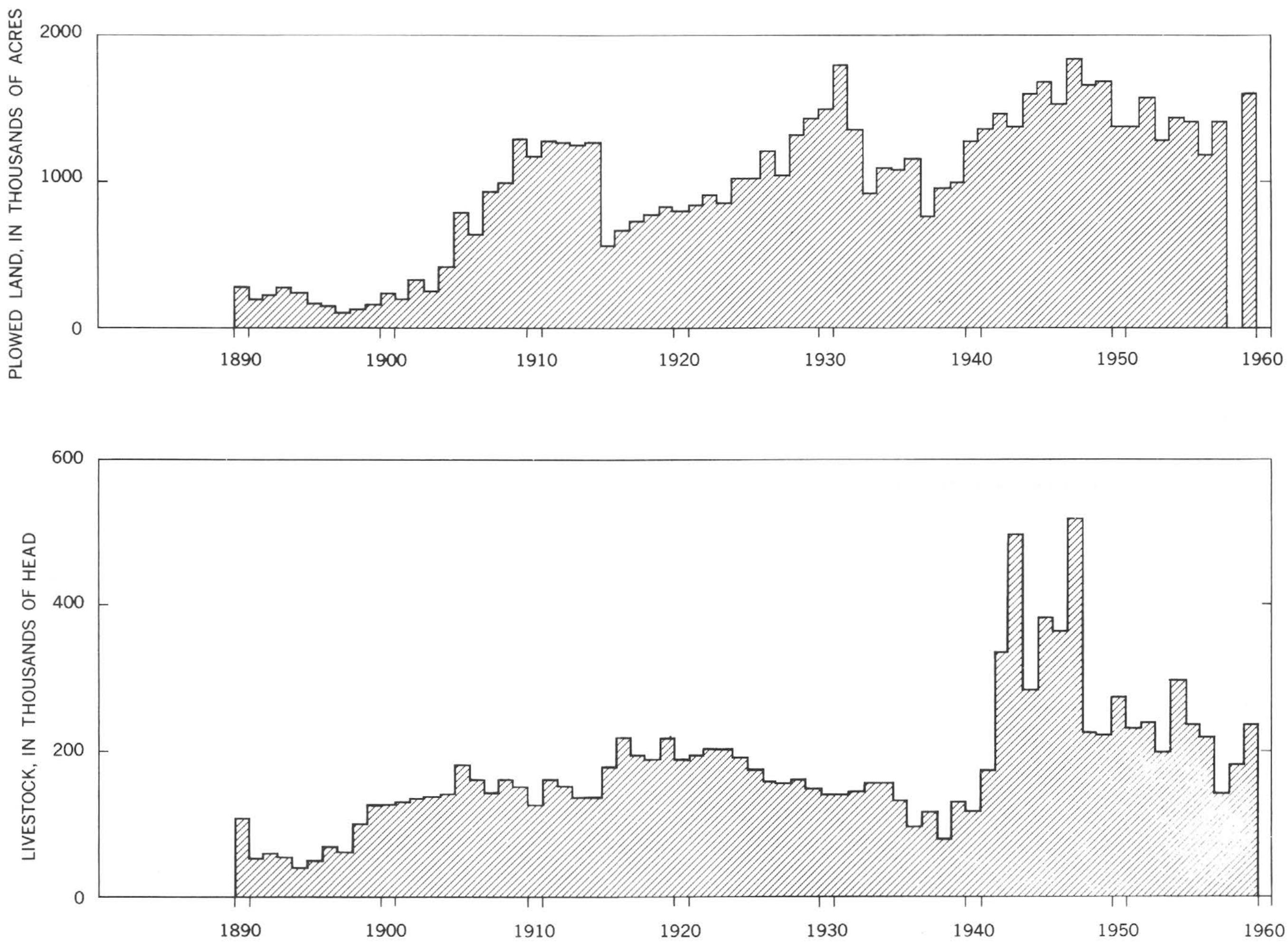


FIGURE 45.—Acres of plowed land and number of head of livestock in southwestern Kansas (Stanton, Morton, Grant, Stevens, Haskell, Meade, and Clark Counties) from 1890 to 1959. Data from annual reports of Kansas State Board of Agriculture. Information on plowed land for 1958 not available.

the Chicago, Rock Island and Pacific Railroad bridge near section 5 (fig. 42) had undergone extensive flood damage in June 1923, October 1930, and June 1937. This period, therefore, was one of destructive floods.

The period of flood-plain construction, 1943–54, was characterized by floods of low to moderate discharge. Only two large floods occurred after 1942—in May 1951 and July 1958 (table 2). The May 1951 flood approached the 1942 flood in peak discharge, but according to McLaughlin (oral communication), most of the flood waters entered the Cimarron River from North Fork Cimarron River in southeastern Grant County (fig. 42). This flood did not widen the channel appreciably because extensive channel narrowing occurred during the period 1943–54 along the Cimarron River below its confluence with the North Fork Cimarron River. The 1958 flood may have caused minor channel widening, but it obviously did not have the effect of pre-1942 floods, for the period 1955–60 was characterized by stability or only minor channel widening. Therefore, although major floods caused serious flood-plain destruction between 1914 and 1942, the post-1942 floods were not important in this respect.

PRECIPITATION

Although discharge records are incomplete, data on precipitation have been collected for long periods at several weather stations in the Cimarron River drainage basin. Precipitation data were compiled for four stations (Richfield, Hugoton, Ulysses, and Liberal, Kans.) since 1910. The records at each station show virtually the same trends during the period 1910–59, and they were combined to give an average for precipitation in the Cimarron River basin in Kansas (fig. 46).

TABLE 2.—*Peak discharge of the Cimarron River, southwestern Kansas*

[Data from U.S. Geol. Survey Water-Supply Papers. Water-year is from Oct. 1 to Sept. 30]

Water-year	Date	Momentary maximum		Station
		Gage height (feet)	Discharge (cfs)	
1896	Apr. 12	--------	90	Cimarron River near Liberal, Kans.
1914	May 2	13.0	[1] (120,000)	Cimarron River near Mocane, Okla.
1936	--------	--------	[2] (67,000)	
1938	Sept. 5	11.0	23,000	Cimarron River near Liberal, Kans.
1939	July 2	8.70	5,350	Do.
1940	May 8	7.08	2,500	Do.
1941	Sept. 24	10.5	47,000	Do.
1942	Apr. 21	12.1	69,000	Do.
1943	Oct. 20	3.70	625	Cimarron River near Satanta, Kans.
1944	May 30	3.69	2,400	Do.
1945	Aug. 23	5.12	2,560	Do.
1946	May 29	3.96	6,360	Do.
1947	Oct. 7	5.03	2,960	Do.
1948	Sept. 11	4.69	5,330	Cimarron River near Mocane, Okla.
1949	June 7	5.50	10,500	Do.
1950	Aug. 3	4.83	6,320	Do.
1951	May 7	9.94	53,400	Do.
1952	Aug. 23	2.18	1,080	Do.
1953	Aug. 20	3.60	4,650	Do.
1954	Aug. 15	3.81	4,300	Do.
1955	May 22	5.45	11,200	Do.
1956	Aug. 21	3.40	2,460	Do.
1957	May 16	5.08	9,300	Do.
1958	July 8	6.75	21,300	Do.
1959	May 4	3.43	3,360	Do.
1960	June 8	3.70	4,290	Do.

[1] Maximum stage known. Estimated on basis of extension of average-stage-discharge relation (L. W. Furness, U.S. Geol. Survey, Topeka, Kans., written communication).

[2] Estimated on basis of highwater-mark elevation and subsequently defined stage-discharge relation at U.S. Highway 283, 4.3 miles south of Englewood, Kans. (L. W. Furness, U.S. Geol. Survey, Topeka, Kans., written communication).

The data show four periods of significance: (1) 1915–30, a period of great annual variability—years of precipitation in excess of the normal separated by years of drought; (2) 1931–40, a period of great precipitation deficiency; (3) 1941–51, a period of above-average precipitation; and (4) 1952–59, a period of below average precipitation. It is significant that channel widening occurred during periods 1 and 2 of variable or deficient rainfall, whereas channel narrowing occurred during period 3 of excess precipitation.

VEGETATION

The flood plain and banks of the river were vegetated prior to 1914 (fig. 43*A*). The grassed flood plain was relatively stable; however, if bank vegetation was destroyed by the 1914 flood, subsequent floods of lower peak discharge could have continued the destruction of the flood plain. Except for the 5-year period 1917–21, the great variability of precipitation during the period 1914–30 probably was unfavorable for the establishment of new vegetation in the channel or on the banks, and the period of prolonged drought 1930–40 certainly checked the growth of any new vegetation, which might have hindered the further widening of the channel. During the 9-year period of above-average precipitation after 1942, only floods of low peak discharge occurred. After 9 years of above-average precipitation, the major flood of 1951 had only minor effects on the channel, for much of the 1942 channel had been stabilized by perennial vegetation and converted to flood plain (fig. 43*C*). The establishment of perennial vegetation was a great aid to flood-plain formation. The growth of new vegetation and the resulting flood-plain construction were clearly dependent on the climatic and runoff characteristics for the period after 1942.

The period 1954–60 affords an opportunity to check the above theory of flood-plain formation, for it was a period of overall rainfall deficiency during which a large flood occurred. These conditions, according to the previous conclusions, should promote channel widening or at least prevent continued narrowing. The records (table 1) reveal that some widening did occur. The widening was not great, apparently because of the change in flood-plain vegetation since 1914—from grass to trees, grass, and weeds. The trees that border the channel offer considerable protection to the banks, and channel widening may be less easily accomplished under these conditions.

SUMMARY

The period of channel widening was characterized by below-average precipitation and by floods of high peak discharge, whereas the period of flood-plain construction was characterized by above-average precipitation and floods of low peak discharge. The influence of these conditions on vegetational growth is the key to the behavior of Cimarron River. Wet years and low water allow a vigorous growth of perennial vegetation, which stablized the existing deposits and promoted additional deposition. The stabilization of the new flood plain by vegetation was so effective that the floods of 1951 and 1958 did not cause great changes in the valley.

MECHANICS OF CHANNEL WIDENING AND FLOOD-PLAIN CONSTRUCTION

The Cimarron River affords an exceptional example of recent channel and flood-plain modification. The almost complete destruction of the flood plain makes a discussion of the manner of widening hypothetical; however, information from other sources and comparison of Cimarron River characteristics with those of other streams permit some conclusions to be drawn with regard to the manner of channel widening. A comparison of the aerial photographs taken in 1939, 1954 and 1960, information obtained by surveying five cross sections (fig. 42), and examination of flood-plain stratigraphy put a discussion of the flood-plain construction on a firmer basis.

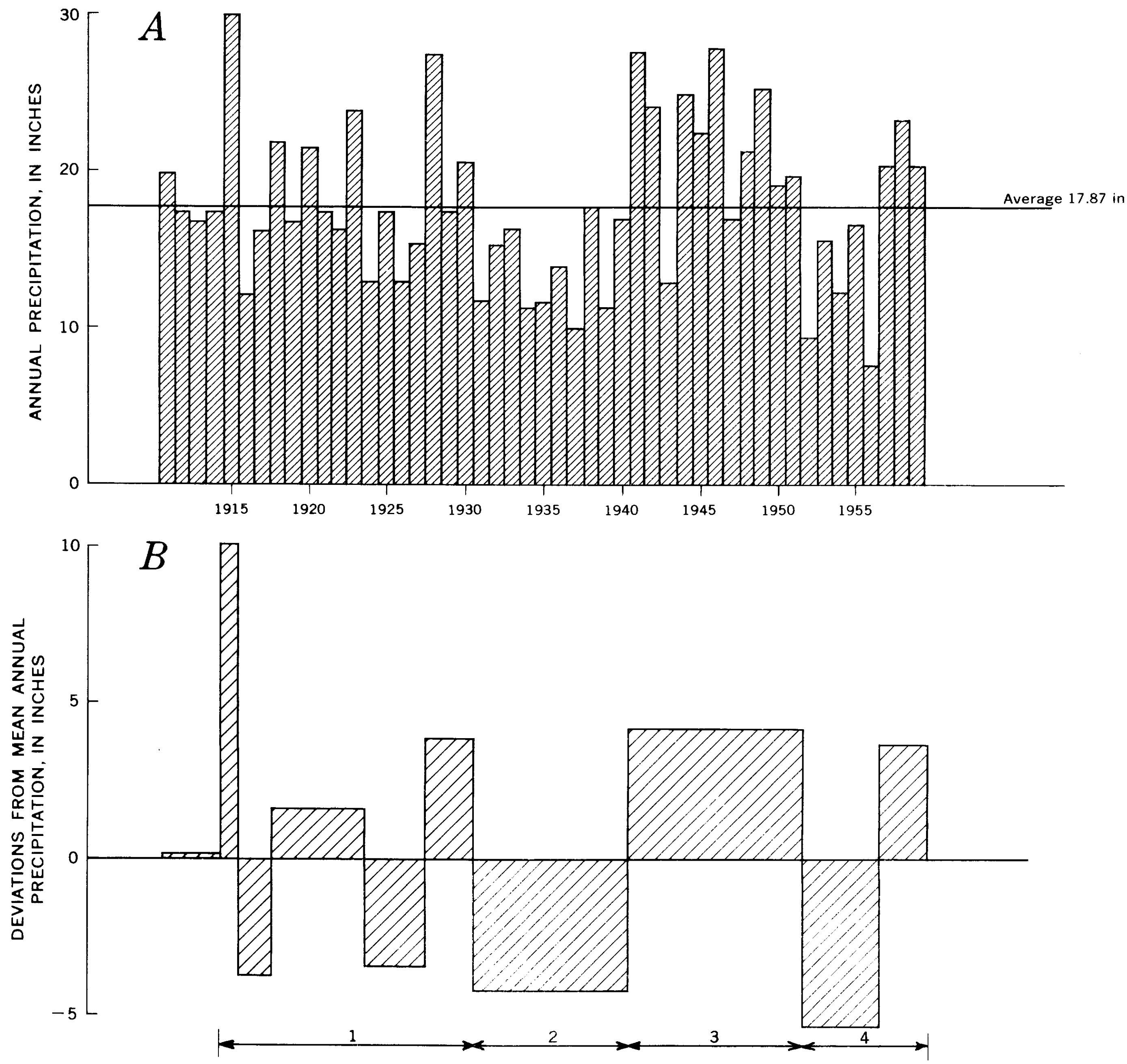


FIGURE 46.—Average annual precipitation in southwestern Kansas, 1910–59. *A*, Average annual precipitation for Liberal, Ulysses, Hugoton, and Richfield, Kans. *B*, Cycles of excess and deficient rainfall. The length of each cycle was determined by inspection of *A*, and the average departure during each cycle was then computed.

CHANNEL WIDENING

The pre-1914 Cimarron River meandered across a grassed flood plain. On the basis of old photographs, the channel was determined in some localities to be as much as 7 feet deep. After the 1914 flood, the channel widened 450 to 600 feet (McLaughlin, 1947). The major flood apparently first destroyed the meander pattern; the point bars were eroded, and the valley was in effect gutted. When the meander belt was destroyed, the protective bank vegetation and finer sediments were removed; the flood-plain sediments beneath the grassed surface were then exposed. The pre-1914 flood-plain sediments are exposed at several localities along the river (fig. 44C). In a sand pit on the north bank of the river at the Highway 56 crossing (fig. 42), 40 feet of alluvium is exposed. Thirty-five feet of the exposure is composed of cross-bedded gravel and coarse sand. Over this lies a dark-colored fine-grained (medium grain size is 0.025 mm) zone that shows the columnar structure of a soil. The structure and dark color of this material suggest that it formed the surface of the pre-1914 flood plain. Overlying this alluvium is from 1 to 2 feet of fine sand and silt on which the present flood-plain vegetation grows. Where exposed the pre-1914 alluvium shows no stratification and appears homogeneous except for the presence of scattered pebbles. The alluvium is dense and cohesive, at least when dry, and may have offered considerable resistance to flood-plain destruction.

At present a part of the pre-1914 flood plain, which escaped destruction, is being eroded at the county road crossing north of Keyes, Okla. The bank on the north side of the river here averages 7 feet in height. The upper 1 to 1½ feet of the bank is composed of sand, which overlies 3 feet of pre-1914 alluvium. Beneath the pre-1914 alluvium, the cross-bedded channel sands are exposed at the base of the bank. The channel sands are being eroded from beneath the cohesive pre-1914 alluvium, causing slumping of the bank into the channel. Widening of the channel is occurring now, and it probably occurred in the past by bank caving that was caused by the removal of sand from beneath the cohesive pre-1914 flood-plain sediment.

EFFECT OF CHANNEL WIDENING ON GRADIENT

The gradient of the channel, as it was converted from a meandering to a straight channel, must have steepened appreciably. The gradient steepened from somewhat less than the gradient of the valley to a value probably closely approaching that of the valley itself. McLaughlin (1947) concluded that some degradation occurred during and after the 1914 flood. This conclusion is based on the formation of tributary gullies along the widened channel and on the reappearance of streamflow near the Highway 56 crossing, about 1 mile farther upstream in 1943 than prior to 1914. Gully formation, however, can be explained by the shortening of tributary stream courses by channel widening, which would induce erosion in the tributary valleys. In addition, part of the upstream migration of the head of the perennial reach near Satanta in 1943 may be explained by a rise in the water table after the floods of 1941 and 1942. Observation wells in the valley alluvium show a rise of water on the order of 3 feet after 1940. Initial channel widening and meander pattern destruction probably were associated with some degradation; but with continued bank erosion, the large amounts of bank sediments added to the channel for transport must have prevented further deepening and probably caused some aggradation of the channel.

Evidence is available to show that during the latter part of the period of channel widening and during the period of flood-plain construction the altitude of the channel floor has not changed appreciably. Data of maximum channel depth, measured from the crown of the roadbed at the time of bridge construction and again in 1960, are presented in table 3. The data show that changes in altitude of the channel are small. A change greater than 1 foot occurred at only one of the six bridges. These data support the hypothesis that degradation and aggradation may have occurred only locally after the 1914 flood; for during the period of flood-plain construction and channel narrowing there has been no consistent change in level along the Cimarron River. Similarly, Coldwell's (1957) observations on the Washita River showed that the river has widened its channel from 100 to 150 feet in 1939 to 200 to 350 feet in 1954 with no change in the altitude of the channel at the Pauls Valley gaging station.

TABLE 3.—*Changes in channel depth between date of bridge construction and 1960*

[Data for date of bridge construction and distance from crown of road to deepest part of channel at date of construction from State Highway Commission of Kansas]

Location of bridge crossing (highway)	Date of bridge construction	Distance from crown of road to deepest part of channel (feet)	
		At date of bridge construction	1960
U.S. 54	1935	20	18
U.S. 83	1948	18	18
U.S. 56	1930	23	24
U.S. 270	1949	32	32.5
Kansas 51	1938	18	17
Kansas 27	1935	12	12.5

FLOOD-PLAIN CONSTRUCTION

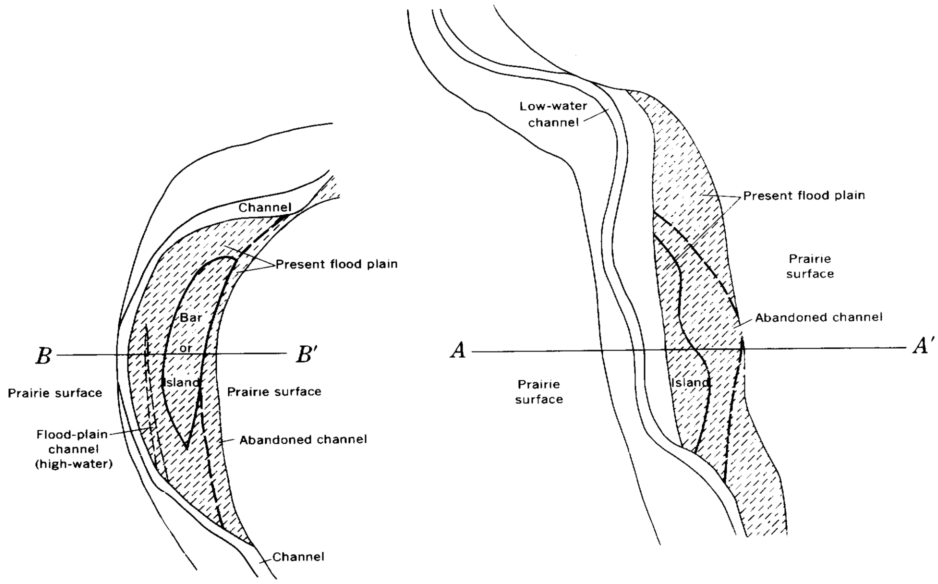
Favorable conditions—namely, above-average precipitation and floods of low to moderate peak discharge—permitted the Cimarron flood plain to begin to re-form after the 1942 flood. Undoubtedly, the fact that the channel was wide enough to occupy almost the entire area of the former flood plain was important.

The new flood plain was built almost entirely by a vertical accretion of sediments, which occurred in two ways as follows: (1) By island formation in the channel and subsequent attachment of the island to one bank by channel abandonment and (2) by deposition on and building up of areas not occupied by the low-water channel. Each process will be discussed in some detail.

ISLAND FORMATION

In the widening channel, sand bars and dunes formed. Bars that formed during the drought years had little chance of becoming permanent features; however, during years of average or excess precipitation, the growth of vegetation on the higher parts of the channel and on bars was the first phase of flood-plain construction. Vegetation converted the bars to permanent features of the channel.

When the channel was wide and dry, the movement of sand by wind was common. The migrating sand collected in vegetation along the perimeter of islands and built natural levees of wind-blown sand. One of these levee dunes occurs at section 1 and is shown on cross section A–A′ (fig. 47) at 950 feet. Once an island be-



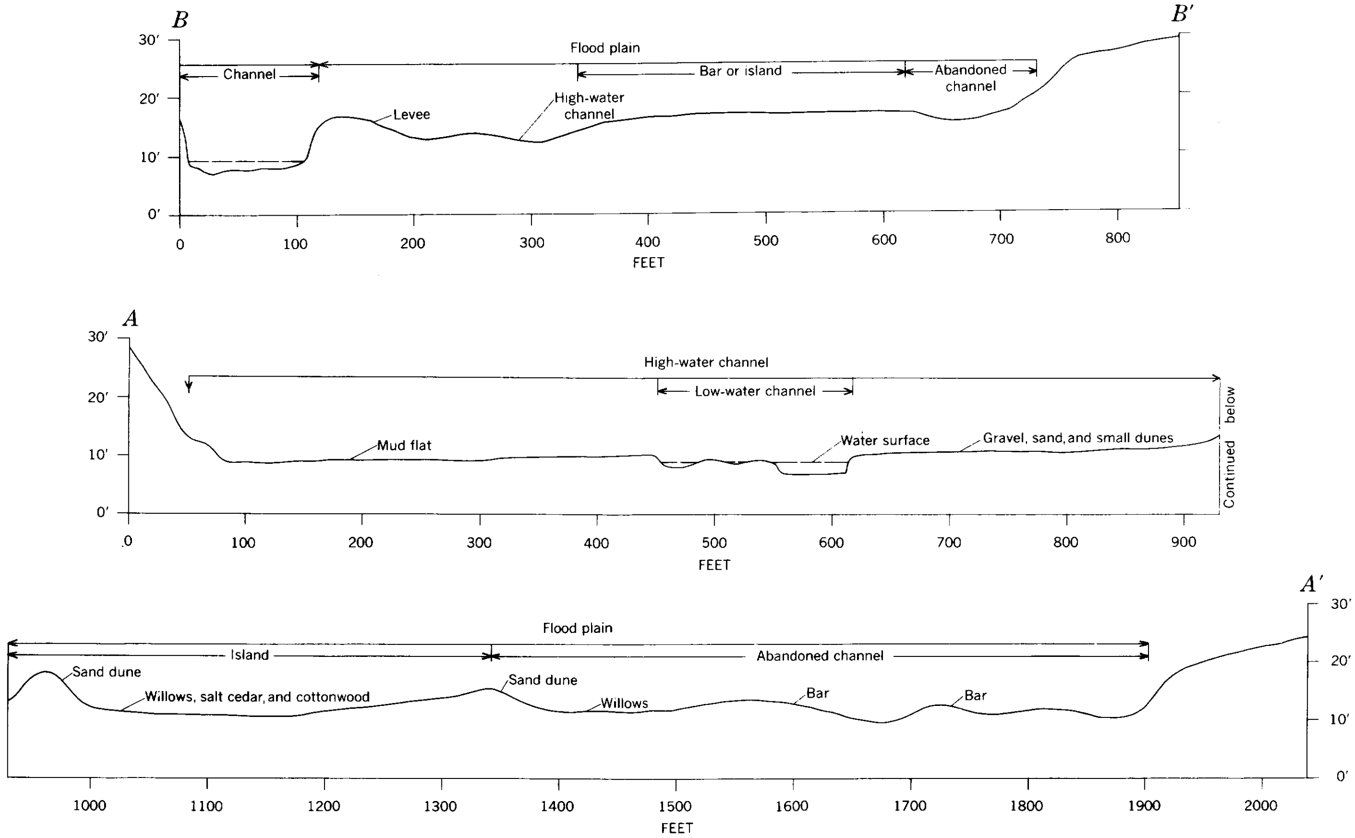


FIGURE 47.—Transverse profiles of the Cimarron River valley. *B–B′*, Cimarron valley near old Highway 270 crossing, cross section 2 (fig. 42). *A–A′*, Cimarron valley at cross section 1 (fig. 42).

came established in the channel, it would be perpetuated by deposition from subsequent floods and by the accumulation of aeolian sand deposits.

The formation of an island narrows the channel, but the presence of the island itself causes further narrowing. Depending on the orientation of the island in the channel, one or the other of the channels surrounding the island will be aggraded and abandoned (fig. 48*A*). For example, an island will rarely be situated so as to divide the water flow equally around the island. Generally, one channel will carry a larger discharge than the other. When this situation occurs, the channel carrying the lesser discharge is a branch channel. Laboratory experiments reveal that at a stream fork the channel which carries the smaller discharge has the highest concentration of bedload (Linder, 1952). In

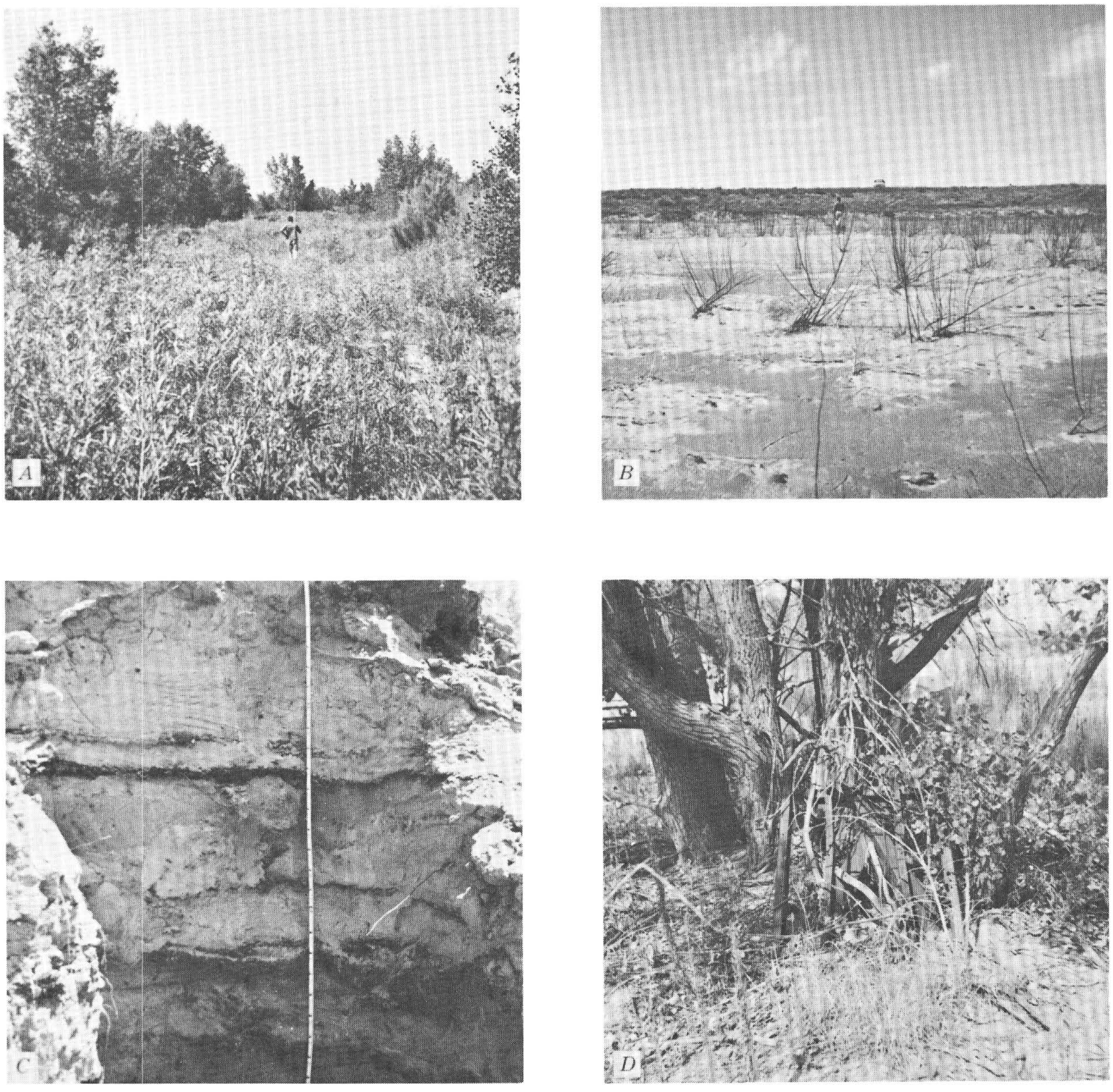


FIGURE 48.—Cimarron River in southwestern Kansas. *A*, Abandoned branch channel near State Highway 51 crossing north of Rolla, Kans., in 1960. On 1954 aerial photographs this channel contained no vegetation. *B*, One-year-old salt cedar saplings growing on mud-veneered part of channel shown at north side of profile *A–A′*, (fig. 47). Light-colored sediment is aeolian sand. *C*, Mud layers in flood-plain alluvium near bridge north of Moscow, Kans. Thin discontinuous mud layer just above thicker continuous layer in upper part of photograph is uppermost mud layer shown on figure 51. *D*, Partly buried automobile frame near country-road bridge north of Moscow, Kans. This frame is one of a group installed to aid bank stabilization. Trees growing to rear of frame are about 15 years old.

perennial streams this relationship may not be important, but in ephemeral streams deposition is important as the flood waters wane. The branch channel would thus be aggraded until it could carry only a minor percentage of the total discharge, and it would soon be abandoned. The cross sections in figure 47 show abandoned branch channels and islands.

The island formation and attachment method of flood-plain formation is less important than it appeared initially, for many islands that occupy the channel of Cimarron River at present were not formed in the channel but were fashioned by the detachment of portions of flood plain by channel changes. The island theory was first proposed to explain flood-plain formation and channel changes along the Red River during the Texas-Oklahoma boundary controversy (Glenn, 1925).

DIRECT FLOOD-PLAIN CONSTRUCTION

If, when the river was at its greatest width in 1943, a low-water channel meandered across the greatly widened sandy high-water channel, then a flood plain may have been already partially formed. Cross section *A–A′* of figure 47 shows the low-water channel occupying the center of a much wider sandy channel. During the survey, water filled the low-water channel. The surface to the left (north) of the low-water channel had been flooded recently and a veneer of mud had been deposited on this surface to a depth of one-half inch. This locality was revisited in the spring of 1961, and the surface was found to be supporting a new growth of salt cedar (fig. 48*B*). The presence of these plants will aid further deposition at this site. Apparently, during years of above average precipitation and low flow, the surface adjacent to a low-water channel becomes vegetated. It is then raised by deposition from flows that overtopped the low-water channel.

Figure 49 illustrates how the flows of different height affect the channel. Low flows are confined to the low-water channel and play no part in flood-plain formation, except as they afford a source of moisture for bank vegetation. Moderate flows escape the low-water channel and deposit sediment on the incipient flood plain, as on the north side of profile *A–A′* (fig. 47). High flows tend either to destroy or to build up the incipient flood plain, depending on vegetational cover.

Because the high flows tend to be destructive during the initial phase of flood-plain construction, the first patches of permanent flood-plain appear on those parts of the valley floor protected from the full force of floods. For example, aerial photographs show that initial flood-plain formation occurred in sheltered parts of the valley, at the mouth of tributaries, and in the lee of islands (fig. 50). The formation of the initial areas of flood plain naturally shielded other parts of the valley floor, which in turn became vegetated and aggraded. The coalescence of these newly formed flood-plain patches formed the existing flood plain. Each succeding flood deposited sediment on these areas, which were gradually built up to a level several feet above the present channel.

FLOOD-PLAIN STRATIGRAPHY

If the foregoing outline of flood-plain formation along the Cimarron River is correct, stratigraphic evidence in the banks of the channel should confirm it. Cross section *A–A′* of figure 47 shows the present low-water channel. The banks of the low-water channel are composed of channel sand. If these banks were built higher by overbank deposition, then each flood should have left a deposit of sand and silt as the flood waters receded from the higher surface. Depending on the sediment load carried by the water and the ability of

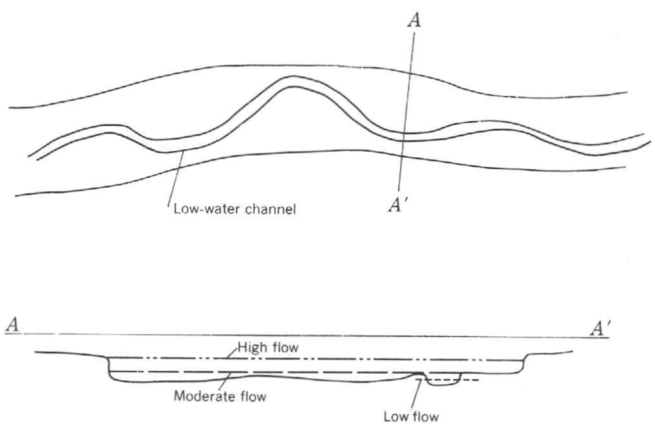


FIGURE 49.—Sketch illustrating parts of the Cimarron valley covered by low, moderate, and high flows. Enlargement of profile, ×4.

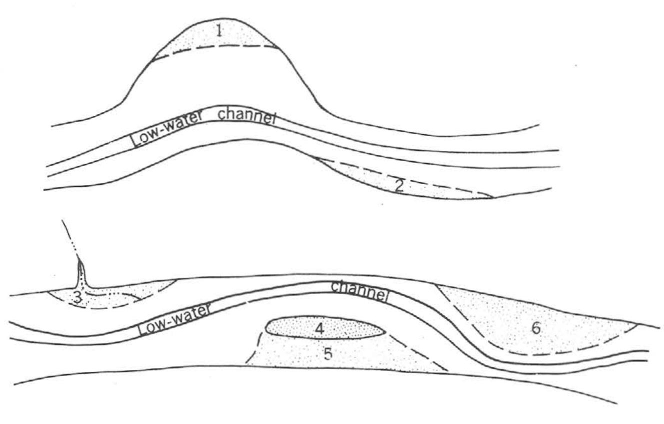


FIGURE 50.—Channel areas favorable for flood-plain formation. 1, Crest of valley meander; 2, Lee of valley bend; 3, Mouth of tributary; 4, Island; 5, Lee of island (abandoned channel); 6, Surface above low-water channel.

the higher surface to trap and hold the sediment, the rise of the flood-plain surface might be rapid or slow. Specific evidence of flood deposition would be a layer of mud left by the receding waters, as observed in 1960 on the left side of the channel. (See section *A–A′* fig. 47, and fig. 48*B*.)

At each reach of the channel visited in Kansas the recent flood-plain deposits, where exposed by excavation, show alternating thin layers of mud and sand (fig 48*C*). The mud layers are horizontal and in some places could be traced back from the channel across the flood plain to the edge of the valley. Individual mud layers were traced in existing sand pits and in holes augered or dug into the flood plain.

To examine these deposits in more detail, a vertical cut, which exposed 5 feet of the flood-plain alluvium, was made near the county road crossing north of Moscow. The base of the cut was at the level of the present channel. A diagrammatic sketch of this section is shown in figure 51. Six mud layers appear in this section (fig 48*C*).

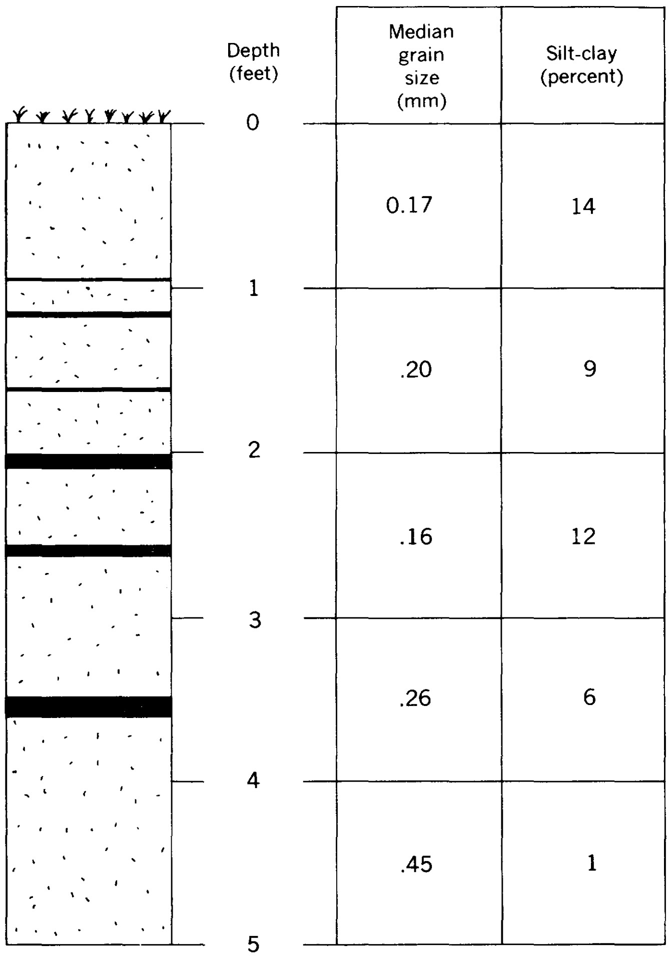


FIGURE 51.—Flood-plain stratification near county-road bridge north of Moscow, Kans. The six mud layers are shown by black lines. (See also fig. 48*C*.)

The flood plain is composed of sedimentary units deposited by overbank floods. A deposit of sand is overlain by a thin layer of fine sediment (the mud layer), which is deposited during the recession of the flood waters. A part of the sand above the uppermost mud layer (fig. 51) is composed of wind-blown sand trapped by vegetation on the flood-plain surface; undoubtedly, a part of the sand found between mud layers is aeolian, for the mud deposited in the channel in 1960 is now covered by a thin veneer of wind-blown sand (fig. 48*B*).

Other evidence of overbank deposition might be a graded deposit; that is, the alluvium exposed in the banks should show a decrease in grain size upward. In figure 51 the grading would be well defined if it were not for the occurrence of two thick mud layers between 2 and 3 feet. Except for the sample containing the mud layers, the percent silt clay also increases upward as expected. The stratigraphic evidence supports the concept of flood-plain formation by vertical accretion.

Cores were taken from several cottonwood trees growing on the newly constructed flood plain in 1961 to afford more precise information on the age of the flood plain. Trees at the south edge of the flood plain near the old Highway 270 crossing were 17 years old. Two trees were cored at the north edge of the flood plain near the bridge north of Moscow. These trees had grown around an automobile frame (fig. 48*D*), one of a group installed to aid in stabilizing the bank. The frame is now located about 250 feet from the present bank of the Cimarron River. The cored trees were found to be 14 and 15 years old. These ages support the conclusion that flood-plain construction began after the 1942 flood.

Trees on the flood plain have been partly buried by alluvium. Pits were dug at the base of three cored trees to determine the depth of burial. One small tree, located on the flood plain near Satanta, was 13 years old in 1961 and has been buried by 2 feet of alluvium. Two trees on the flood plain near the county road crossing north of Moscow and closer to the channel than those shown in figure 48*D* were excavated to the main root system at depths of 1.8 and 2.0 feet. These trees were both 11 years old. This evidence indicates that about 2 feet of flood-plain deposition has occured during the last 11 to 13 years.

SUMMARY

Once started by a major flood, the widening of the Cimarron River channel did not cease because of the ease of bank erosion and the occurrence of large floods. The widening of the channel apparently occurred by bank caving as the coarse sand was washed from beneath the relatively resistant pre-1914 flood-plain sediments.

During channel widening, degradation was probably not important. Channel gradient steepened, however, as the course of the river was shortened by destruction of the meander pattern.

The channel narrowing or flood-plain construction along the Cimarron River was the result of three factors as follows: The river had widened excessively; precipitation was above average; and the large floods were infrequent and did not erode the newly formed flood plain. The new flood plain is composed of a complex of coalesced islands, abandoned branch channels, and areas of flood plain built adjacent to the low-water channel. Large parts of the wide channel were not occupied by low-water flows, and these areas were sites of vegetational growth. The increased plant cover reduced flow velocities over these areas and promoted sediment deposition.

An examination of flood-plain stratigraphy indicates that the flood plain is composed predominantly of overbank sediment deposited during floods. An individual flood deposit consists of a layer of sand covered by a veneer of mud.

COMPARISON OF CIMARRON RIVER CHANNEL CHANGES WITH THOSE OF OTHER RIVERS

Too often in the consideration of unstable channels one is prone to think only of degradation or aggradation of the channel. Observations along Cimarron River clearly show, however, that both channel widening and narrowing may occur without a major change in the altitude of the channel floor (table 3). The rate and method of flood-plain formation noted along the Cimarron River is not unique, for similar changes have been noted along other rivers. For example, the widening of the channel of Washita River, as described by Coldwell (1957), occurred without significant changes in the altitude of the bed of the stream.

Hefley (1935) stated that the Canadian River in eastern Oklahoma has widened since the major flood of 1906 from less than half a mile to more than 2 miles in some places.

Bryan (1927) reported that the Rio Salado, a tributary to the Rio Grande near San Acacia, N. Mex., ranged from 12 to 49 feet in width in 1882, but in 1918 its width ranged from 330 to 550 feet. Bryan (1927, p. 19) stated that "Unlike many similar streams in New Mexico, which have not only widened their channels but deepended them in the same period, the Rio Salado, at least in the vicinity of Santa Rita, has even yet banks that are only 3 to 10 feet high and average 5 feet high." Leopold and Wolman (1957) reported that the channels of the Verde and Gila Rivers in Arizona were widened by large floods, but that narrowing of the channel followed establishment of vegetation. These changes may be similar to those which occurred along Cimarron River.

Smith (1940) reported on recent channel changes of several rivers in western Kansas, indicating that they have undergone Cimarron-type changes. The Smoky Hill River originally "had alternating sandy stretches and grassy stretches with series of pools. Later the former were widened, and the latter were sanded up * * *." Smith further stated that the Republican River was greatly affected by the flood of 1935.

> Formerly a narrow stream with a practically perennial flow of clear water and with well-wooded banks, the Republican now has a broad, shallow sandy channel with intermittent flow. The trees were practically all washed out and destroyed, much valuable farmland * * * was sanded over, and the channel has been filled up by several feet.

The Republican and Smoky Hill Rivers are typical of streams having sandy channels, as they have only from 2 to 5 percent silt and clay, in the sediment forming the perimeter of their channels (Schumm, 1961).

The Red River flood plain near Burkburnett, Tex. (fig. 52) was the object of intensive study as a result of the boundary dispute between Oklahoma and Texas (Glenn, 1925; Sellards, 1923). The Red River was never a narrow, meandering stream in historic times: a survey in 1874 showed the river to be about 4,000 feet wide. The channel, however, has undergone some important changes. For example, comparison of a special map prepared in 1920 (Sellards, 1923) with aerial photographs taken in 1953 showed enlargement of the flood plain. Over a 10 mile reach of the river 5.5 square miles of flood plain were added. The width of the Red River was measured at 20 sections between the confluence of the Pease and Red Rivers to the west and the confluence of Whiskey Creek and Red River to the east on aerial photographs taken in 1937, 1953, and 1957. In 1937 the river averaged three-quarters of a mile in width, close to the average for the 1874 survey. In 1953 the average width had decreased to half a mile. This channel narrowing may have been contemporaneous with that along Cimarron River. In 1957 the river averaged two-thirds of a mile wide, indicating a significant widening between 1953 and 1957. The photographs show all the types of flood-plain formation noted along the Cimarron River (fig. 50), and as suggested by Glenn (1925), the attachment of islands to the flood plain was important in the formation process.

The Red River transports large amounts of sand, red silt, and clay. The flood-plain sediments, where observed near the main highway bridges (Highways 81,

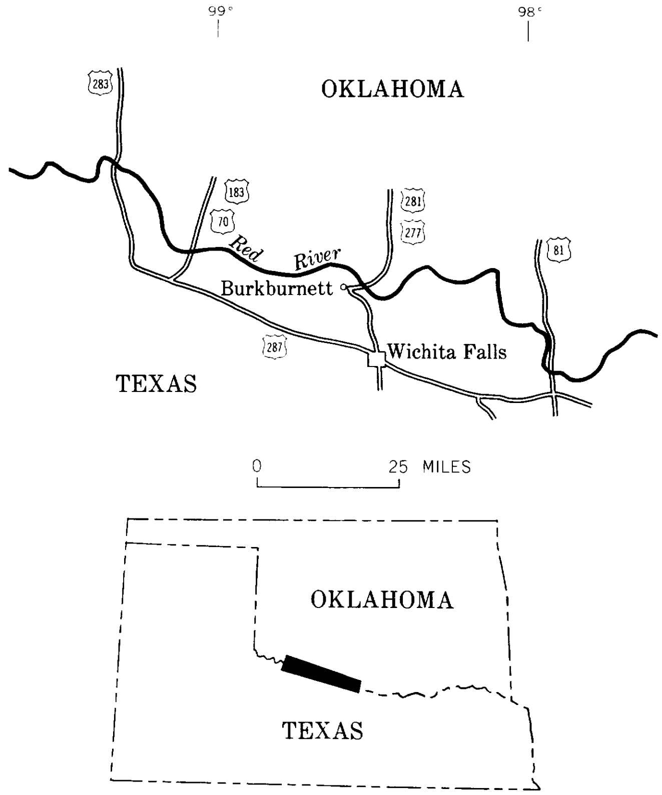


FIGURE 52.—Index map of Red River area.

281, and 183, fig. 52) show stratification characteristic of vertical accretion deposits. One section was sampled in detail near Burkburnett, Tex., where it was possible to obtain a sample of one thick mud layer not mixed with sand. The median grain size (0.002 mm) and silt and clay content (89 percent) of this layer are very similar to the median grain size (0.001 mm) and silt and clay content (85 percent) of mud recently deposited over sand at the margin of the channel. The similarity between the mud layers of the bank and the mud being deposited in the channel and the occurrence of mud layers in the banks at this location and elsewhere indicate that the Red River flood plain and islands, where observed, are built by the vertical accretion of sediment.

SUMMARY

The channel changes along the Cimarron River appear to be similar to changes which have occurred along the Washita, Canadian, Smoky Hill, Republican, and Red Rivers and Rio Salado. The changes differ from the degradation and aggradation characteristic of other unstable streams, for these rivers widen and narrow their channels as an alternative to aggradation and degradation

CONCLUSIONS

Flood-plain destruction along the Cimarron River occurred as a result of channel widening, which was initiated by the maximum flood on record. Large floods and below-average precipitation hindered a return to stability, and, in fact, were the means by which flood-plain destruction was perpetuated.

In contrast to floods observed in humid regions (Wolman and Eiler, 1958), floods in semiarid and arid environments may be tremendously destructive to the channel and flood plain. This destruction by floods may be a characteristic of erosion in a semiarid region where climatic fluctuations are common, and the streams are ephemeral or carry very low flows during long periods. Often these streams cannot adjust as readily as perennial streams to a change in stream regimen or a climatic fluctuation. Large floods may trigger an adjustment by initiating periods of severe erosion or deposition (Schumm and Hadley, 1958), and the events along Cimarron River may be of this type.

Most of the Cimarron River flood plain was constructed in only 12 years. Although rapid rates of erosion and deposition are commonly observed on other rivers, we are not aware of rates of flood-plain formation elsewhere as rapid as on the Cimarron River.

Observations in the valleys of the Cimarron and Red Rivers show that the flood plains were formed predominantly by overbank flooding and the vertical accretion of sediment. Generally, patches of flood plain in the most sheltered parts of the channel formed first. These patches coalesced and joined the islands and abandoned channels to form a composite flood plain. The flood plain, however, can be built simultaneously over large areas when an area of channel between the low-water channel and the edge of the valley is transformed as a unit to flood plain (fig. 50).

After the flood plain has been formed by vertical accretion, the stream may begin to meander. This reworking of the flood-plain alluvium by lateral migration of the stream would form a flood plain composed predominantly of lateral accretion deposits, as described by Wolman and Leopold (1957) and Adler and Lattman (1961). A flood plain may be formed by different processes, but a meandering stream migrating from one side of the valley to the other would leave a flood plain showing stratigraphic evidence only of lateral accretion. Therefore, the presence of lateral-accretion deposits forming the major part of a flood plain may not mean that the flood plain was initially formed by point-bar construction.

The type of changes occurring along the Red and Cimarron Rivers can be attributed to a large extent to the sandy alluvium forming the flood plain and channel. Channel widening instead of degradation and flood-plain construction instead of aggradation may occur commonly along sandy rivers in semiarid regions.

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